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Inlet Spits and Maintenance of Navigation Channels

by Nicholas C. Kraus and William C. Seabergh

PURPOSE: The Coastal and Hydraulics Engineering Technical Note (CHETN) herein provides information on the formation and behavior of sand spits at inlets. Their interaction with navigation channels and possible consequences for water exchange are discussed. A mathematical model is presented to estimate spit development, and an example of physical modeling of spit evolution is given to illustrate properties of spit growth at inlets and model capabilities.

BACKGROUND: Spits are organized surface-piercing accumulations of sediment that grow by transport directed from a landmass or sediment source toward a water body. Spits can form at the ocean, lake, or bay sides of inlets, entrances, and river mouths, and they must be managed at navigation channels and inlets. Inlet or river closure through spit development has implications for water exchange, as well as for commercial and recreational navigation. Submerged shoals that grow from larger landmasses, such as tip shoals that form around the ends of jetties can be considered subaqueous spits that are governed by some of the same processes.

Many major barrier islands were developed as spits that emanated either from sediment sources on the mainland or from sediment discharged at river mouths. A well-known example of spit growth is Democrat Point, located on the western end of Fire Island on the south shore of Long Island, NY. This spit has grown from sediments supplied from mainland deposits located updrift – to the east (Figure 1). The U.S Army Engineer District, New York, studied the westward growth of Fire Island in the early 1950s (Gofseyeff 1953; Saville 1960) to determine maintenance requirements for Fire Island Inlet. Jetty construction from 1939 to 1941 was conducted to arrest growth of the spit, which had been driving the navigation channel westward. By 1950, the jetty was fully impounded, and the estimated 450,000 yd^3 (340,000 m^3) of sand transported westward bypassed the jetty, creating spits. The recent photograph of Fire Island Inlet shown in Figure 2 reveals several spits comprised of material that has been transported past the jetty. As a result of the presence of these spits, the navigation channel runs parallel to the shore at Oak Beach and the shore located westward (Figure 1) for considerable distance before boats can turn south and seaward.

Much of the modern barrier island system of Texas was formed from sediment deposits from its river system that includes the Brazos River, Colorado River, and Rio Grande River. The two arrows in Figure 3 indicate the course of spit development at the mouth of the Colorado River, where the net longshore transport is directed from east to west (right to left in the figure). At the time of the photograph, the Federal navigation channel was being constricted by spit growth from the east, built from sediment passing through the shore-connected weir on the east jetty. The spit to the west is comprised of sediment eroded from the landward side of the west jetty and, possibly, by sand transported around the relatively short west jetty during times of reversal (Lin, Kraus, and Barcak, in preparation).

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14. ABSTRACT
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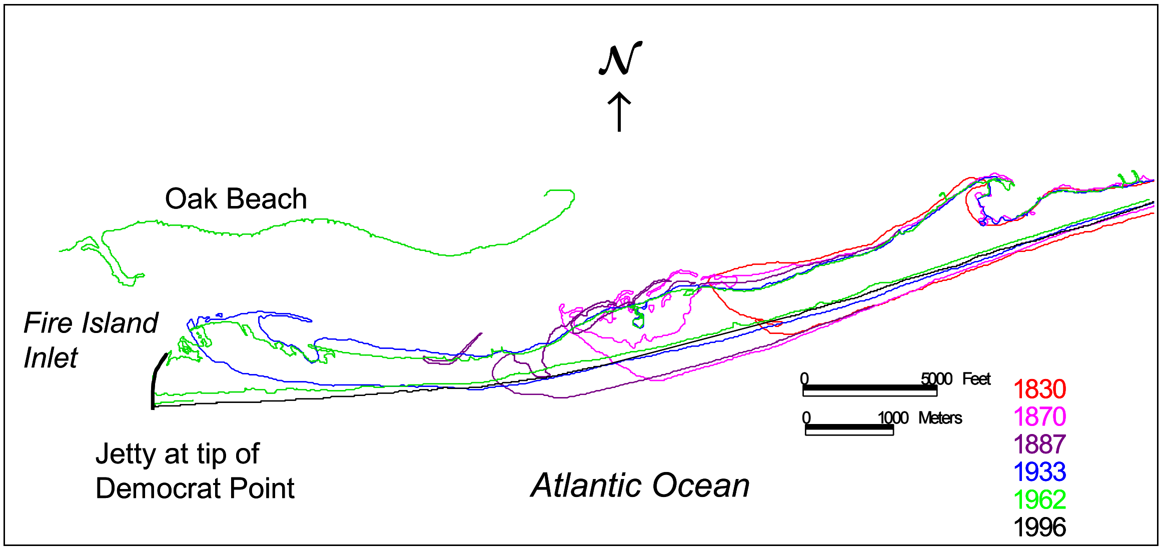

Figure 1. Spit growth at Fire Island Inlet, NY

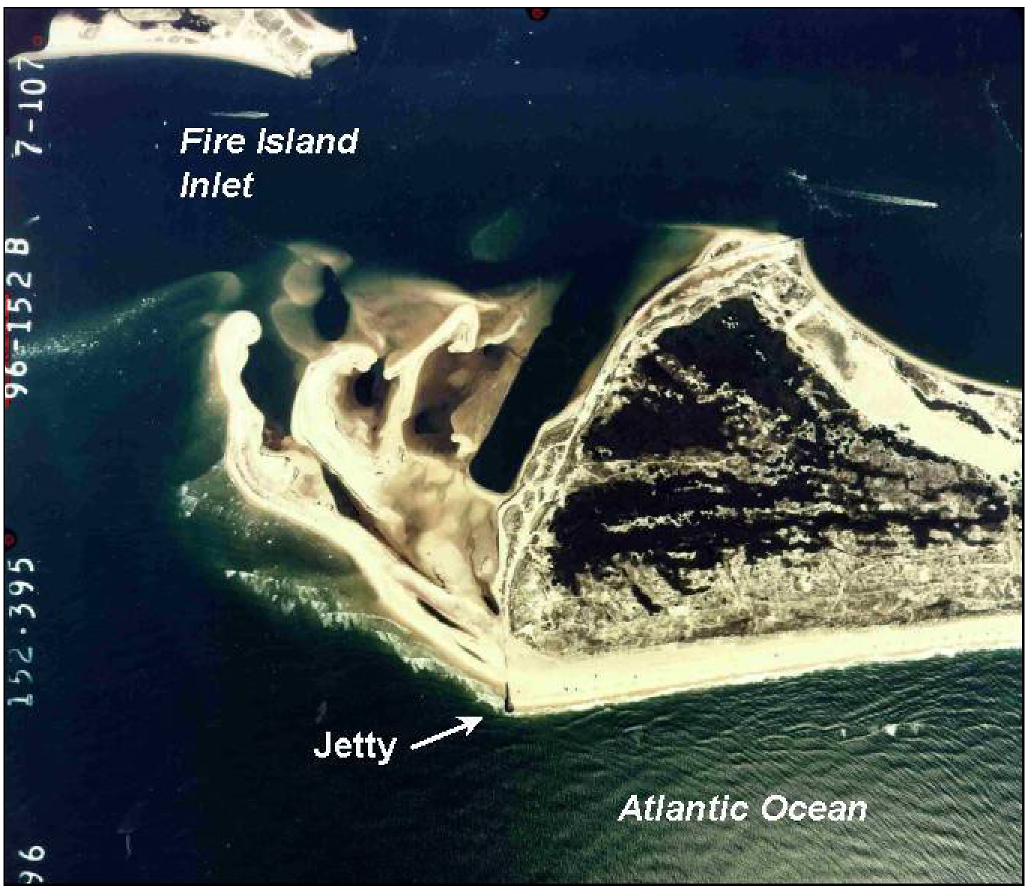

Figure 2. Multiple spits at Fire Island Inlet, NY, 1996

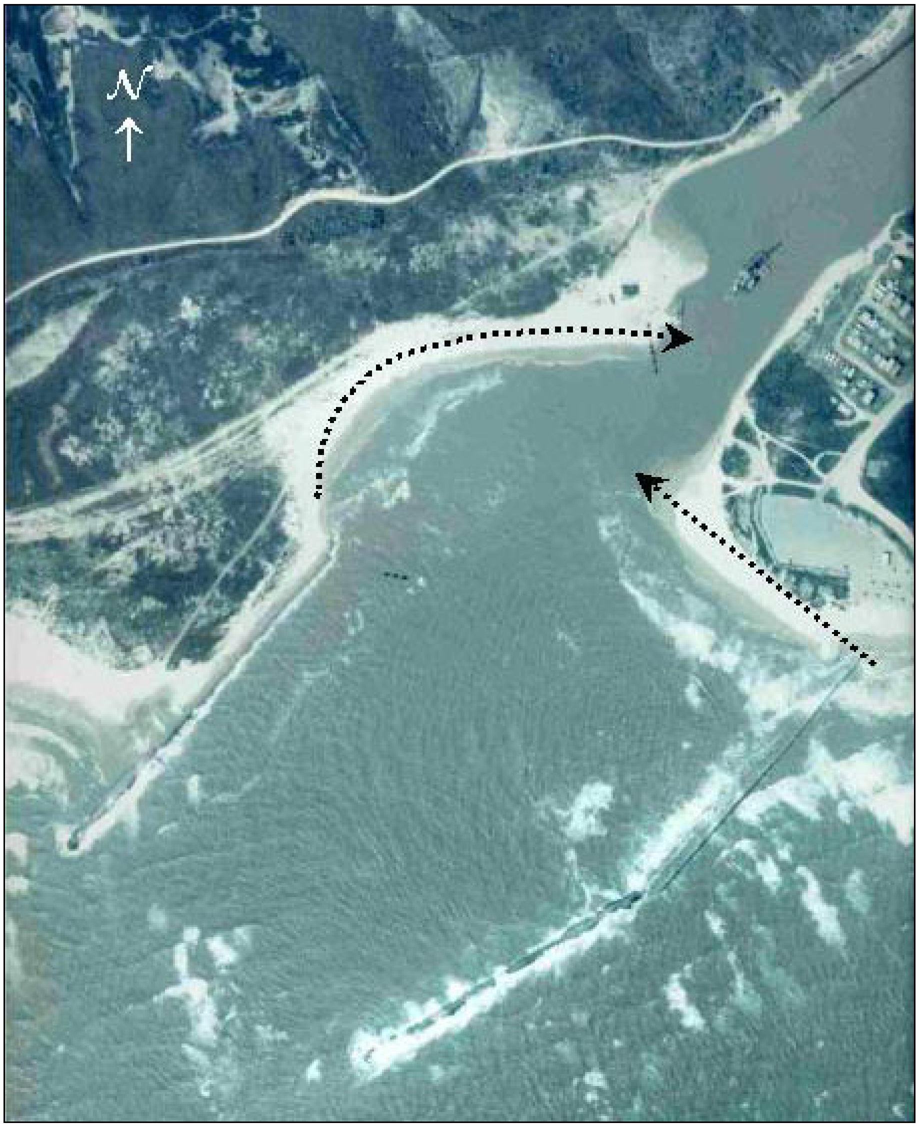

Figure 3. Mouth of Colorado River, TX, August 2000

On a shorter time scale, spits develop locally from sand sources such as the beach or a shallow shoal. In many unstructured inlets, the formation of sand spits governs the movement, or migration, of a coastal inlet and its navigation channel. The presence of spits can be acceptable if the change in location of the channel is not too rapid, authorized channel width and depth are maintained, and channel curvature is minimal. If high rates of spit growth occur, channel depth may be lost and location changes can become a hazard to navigation. At structured inlets, spit development can occur at jetty tips if pathways extend from a sediment supply area along the beach or offshore shoal. If the structure is relatively low or permeable, and the local sand supply is significant, spits can form within the structured system from sediment moving over and through the structure. Movement of sand over a weir jetty is typically in the form of a spit that emanates from the local shoreline.

Figure 4 summarizes potential shoaling problems at navigation channels related to spits, either emergent or submergent. Tip shoals commonly occur at inlets where there is a predominant direction of longshore transport and may be subaerial, as in Figure 2 or, more commonly, submergent. Wind can blow sand over jetties and create spits, and these tend to occur where the beach is dry most of the time. If there is no shoal, spits commonly appear at the ends of barrier islands or landmasses in a continuing process of land extension. Islands composed of dredged material or natural islands exposed to strong currents will deform, with wing spits emerging on both sides.

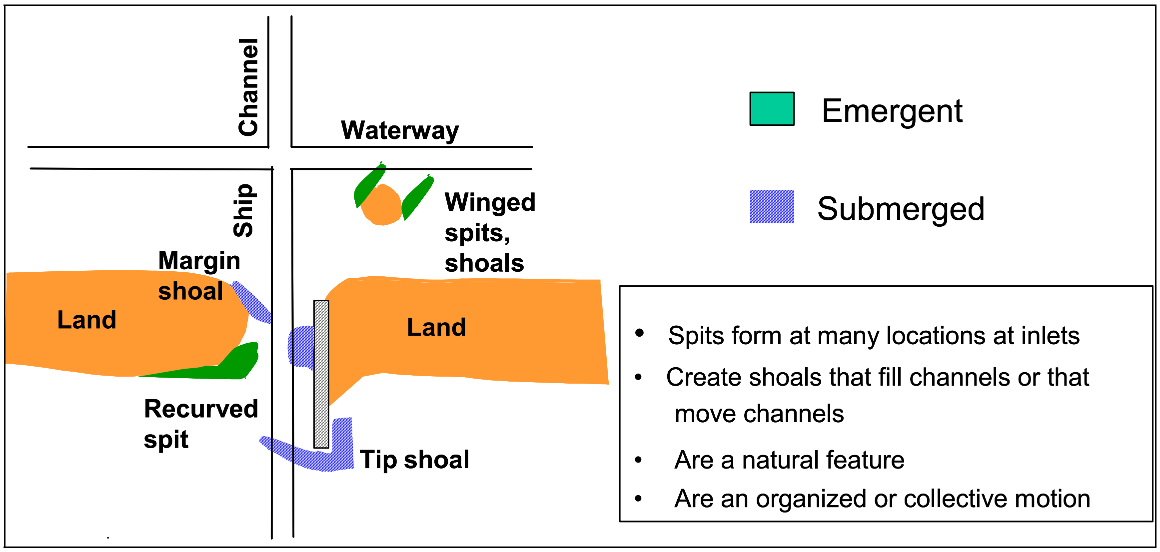

Figure 4. Common types of spits

The forces that create spits are typically related to waves and wave-generated currents, with tidal currents a shaping force changing spit orientation. At an unstructured inlet, if there were no tidal current and waves approached at some angle to the shore adjacent to the inlet, the spit would be expected to progress on the same alignment as the shoreline into the inlet channel. Typically, tidal currents are present, and the spit wraps into the inlet entrance by sediment transported with curvature of the flood current that accelerates as it converges into the inlet. Ebb currents tend to be more centrally located in the inlet and so do not change the spit except to erode its tip if the spit protrudes into the channel.

COASTAL SEDIMENT PROCESSES DETERMINING SPIT DYNAMICS: The classic work in the field of spits is the book edited by Schwartz (1972). Based on a laboratory physical-model study and interpretation of field evidence, Meistrell (1972) introduced the concept of "spit-platform," comprised of a spit or ridge above mean low water level that resides on the platform – a sedimentary structure elevated above the ambient shelf, but below mean low water. Meistrell (1972) found that growth of the platform preceded formation of the spit. Here, the term "spit" will represent both the subaerial ridge and platform, unless otherwise stated. Kumar and Sanders (1974) subsequently described the structure and evolutionary processes of spits in nature.

Factors controlling the development and evolution of spits can be identified through observations such as the ones previously described and understanding of the acting coastal processes. For

example, spits exposed to similar tidal range and waves or along the same coast are expected to have the similar width, elevation above mean water level and, possibly, speed of growth. Table 1 presents a classification of spit macro-properties and processes by time scale (Kraus 1999).

Table 1
Parameters Controlling Inlet Spit Geometry and Evolution, and Associated Processes

Spit Parameter	Short Term	Long Term[1]
Length	Longshore transport rate; proximity to inlet channel; strength of channel current	Sediment supply; geologic controls; breaching (bayward or seaward); cyclic & intermittent forcing
Elongation speed	Longshore transport rate; grain size; proximity to inlet channel; beach slope and depth-contour gradients parallel to spit	Cyclic and intermittent forcing[2]
Width	Runup elevation; tidal range; depth-contour gradients perpendicular to spit	(see overwash fans, next row)
Overwash fans	Storm surge; frequency of storms	Dunes and other blocking features; depth of receiving bay or lagoon
Elevation above msl	Runup; tidal range	Aeolian transport; relative sea-level change; tsunami
Depth of closure	Wave height and period; tidal range; grain size	Extreme storms; elapsed time
Tendency to recurve	Proximity to channel; channel current; wave focusing; extreme storms	Cyclic and intermittent forcing

[1] Long-term processes encompass those of short-term processes in same category.
[2] Cyclic and intermittent forcing arises from seasonal and annual changes in wind and waves, arrival of storms and weather fronts, annual and interannual change in water level, etc.

Elevation of a berm depends primarily on wave uprush or runup. By Hunt's formula, runup depends linearly on wave period and only as the square root of wave height. Therefore, wave period enters prominently in creating spit volume – its width and elevation. Greater tidal range carries the runup to greater elevation, increasing spit elevation. Over the long term, frequency, direction, and strength of the wind will determine the degree of dune formation and width of a spit.

Temporal variability in forcing includes weather cycles on scales from days to global weather patterns over decades, such as El Niños, and intermittence in sediment supply as from river discharges and variations in direction of longshore transport. Intermittence in sediment supply as from reversal in transport may have direct bearing on spit recurving.

EXAMPLES: In this section, three examples are given to illustrate the behavior of spits and consequences for navigation and dredged-material disposal projects.

Corpus Christi (North) Beach, TX. Corpus Christi Beach, called North Beach by the residents, is a bay shore, north-south trending beach located on the western side of Corpus Christi Bay. The beach terminates at the north jetty of the Port of Corpus on its southern side and is now terminated by a groin 2.3 km to the north on its northern side. Corpus Christi Beach is a popular urban recreational area that began eroding notably after a series of hurricane landings in the early 1900s.

In March 1978, the U.S. Army Engineer District, Galveston, finished renourishment of the beach as an innovative two-layer beach fill consisting of 382,000 m^3 of hydraulically-dredged silty sand covered by 300,000 m^3 of coarser (0.4 mm median diameter) sand hauled by truck from an inland source (Kieslich and Brunt 1989). The thickness of the sand cover ranged from 0.5 m on the berm and to 0.9 m on the foreshore. Williams and Kraus (1999) review the hydrodynamics and meteorology of Corpus Christi Bay.

Cost-sharing non-Federal partners for the project did not construct the planned terminal groin on the north end of the fill. As a result, the northern end of the beach experienced an average-annual loss of 9,200 m^3 for the 5-year postconstruction period, about 70 percent of the total measured loss of the project. The loss on the northern end was predominantly by spit elongation northward toward Nueces Bay. By 1982, the spit had extended more than 600 m to the north, where the Nueces Bay causeway obstructed further lateral movement, and the spit began to widen where it impinged on the causeway. Figure 5 illustrates the rapidity of the spit growth. Already in October 1980, the distal end of the spit had to be dredged to allow access to a marina located near the causeway.

Figure 5. Growth of spit at north beach toward highway bridge and channel, lower left (north is to bottom of figure)

Figure 6 shows that the width of the spit increases toward the distal end. The increase is attributed to recurving of the spit by the tidal current and by the susceptibility of the newer, hence, lower portion of the spit to overwash during storms and times of elevated water level. Although cross sections of the spit are not available, limited data are available for the beach nourishment project area. The profile of the spit (Figure 7) is expected to close at the flat bay bottom, approximately 2.5 m below the Galveston District navigation datum called mean low tide (mlt). The spit approached the navigation channel passing under the bridge, as well as began to cut off the entrance channel to a marina. Therefore, the distal end of the spit had to be dredged.

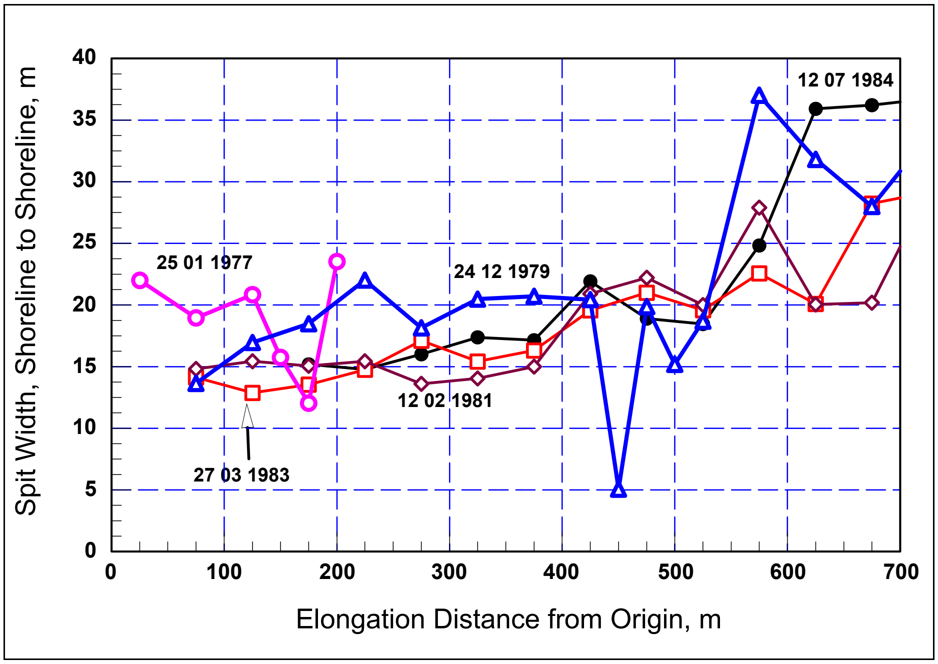

Figure 6. Width of spit as function of distance from origin of spit

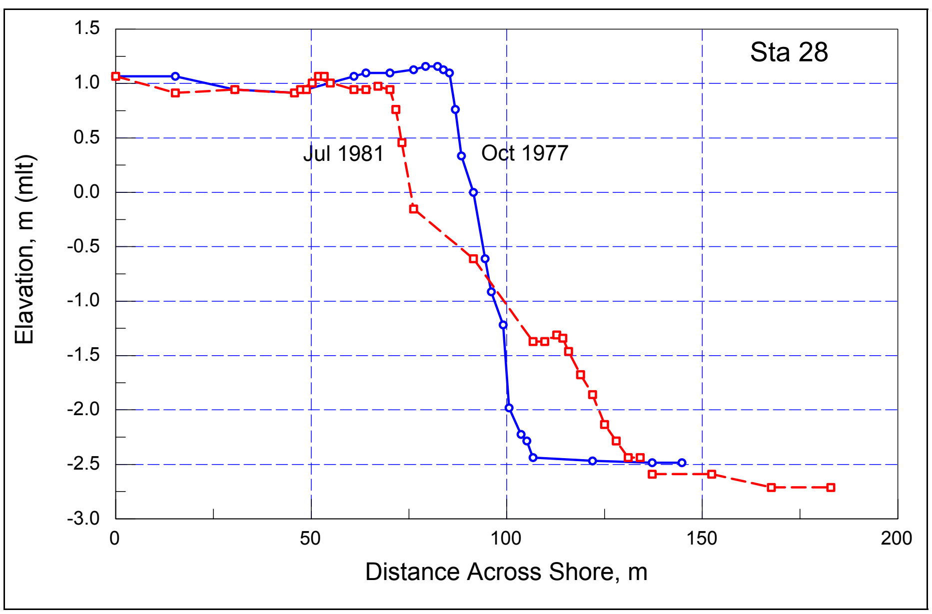

Figure 7. Cross section of beach immediately after nourishment and 5 years later

San Bernard River Mouth, TX. The San Bernard River is a small stream running almost north-south. It crosses the Gulf Intracoastal Waterway (GIWW) approximately 2 km north of its mouth at the Gulf of Mexico, which is located approximately 6 km south of the Brazos River mouth (Figure 8). Despite river regulation, the Brazos River still remains a major source of sediment for the north-central coast of Texas. Longshore transport along this portion of the Texas coast is from east to west. Neither the Brazos River mouth nor the San Bernard River

mouth are Federal navigation projects, but closure of the San Bernard River mouth due to spit migration and closure prompted the Galveston District to consider remedial measures to maintain the mouth so as to reduce the strength of the river flow redirected along the GIWW.

Figure 8 shows two apparent prominent spits at the river mouths, one directed to the east at the Brazos River and the other directed to the west at the San Bernard River. However, the apparent spit at the Brazos River mouth is a relict entrance bar brought by a large flood in 1992. The many beach ridges trending northeast - southwest from the Brazos River mouth indicate welding of such entrance bars to shore. The older beach ridges are vegetated, as opposed to the spit at the San Bernard River mouth, which consists primarily of unvegetated sand.

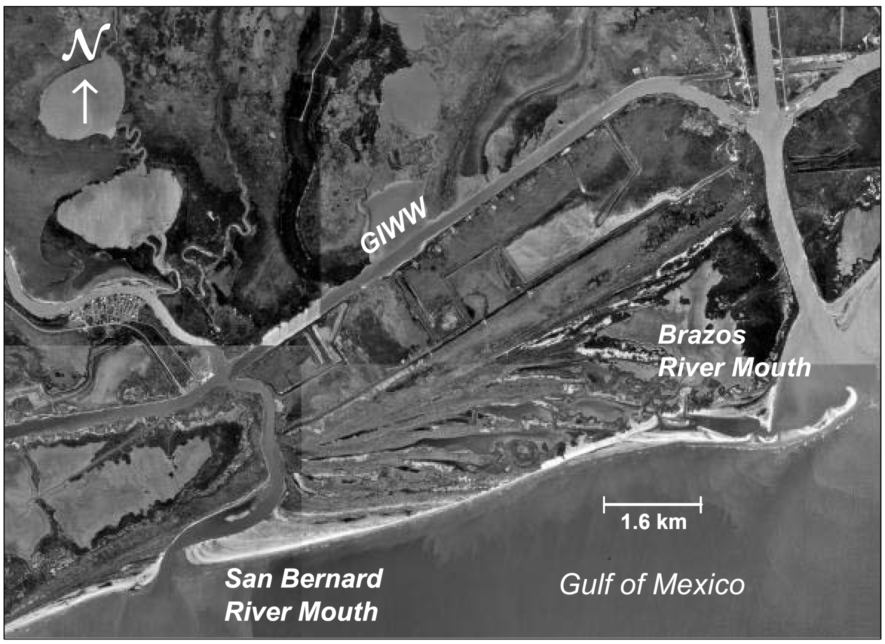

Figure 8. Spits at the Brazos River mouth and San Bernard River mouth, 1995

Aerial photography of the area was rectified and brought to a common coordinate system. Application of the BeachTools Geographic Information System package (Hoeke, Zarillo, and Snyder 2002) for identifying the perimeter of the spit through time produced spit outlines as shown in Figure 9. From these outlines, the length and width of the subaerial portion of the spit could be tracked through time, as well as the width of the river mouth (Figure 10). The spit grew almost linearly with time, while maintaining almost constant width of 200 m. From this information, an average-annual westward-directed longshore sediment transport rate of about 150,000 m^3/year was determined (Kraus and Lin, in preparation).

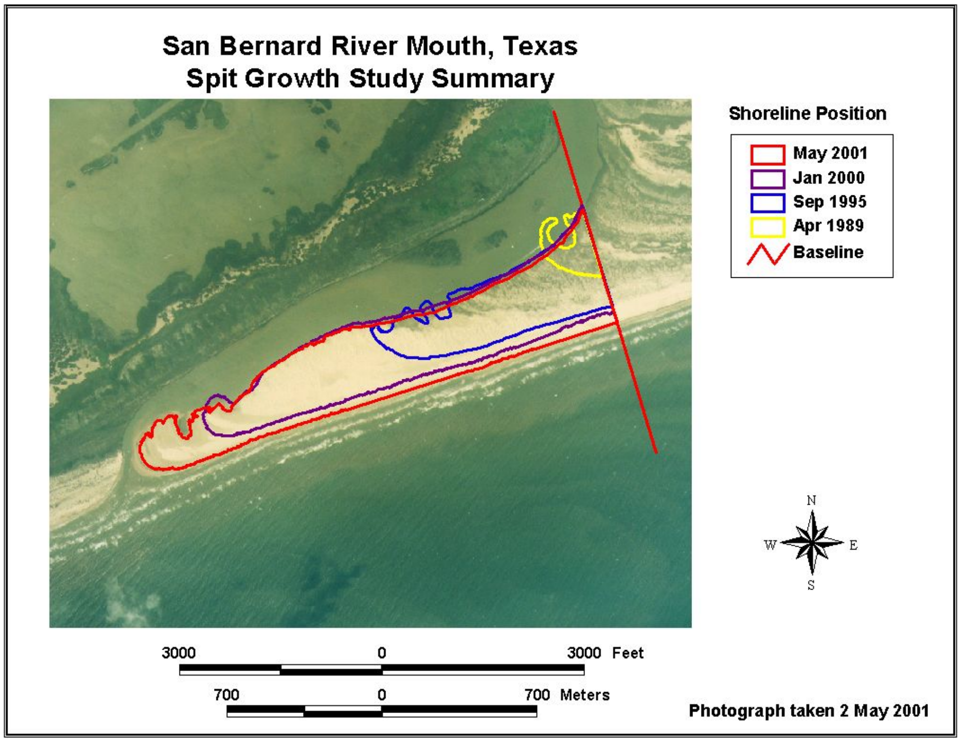

Figure 9. Spit growth at San Bernard River mouth

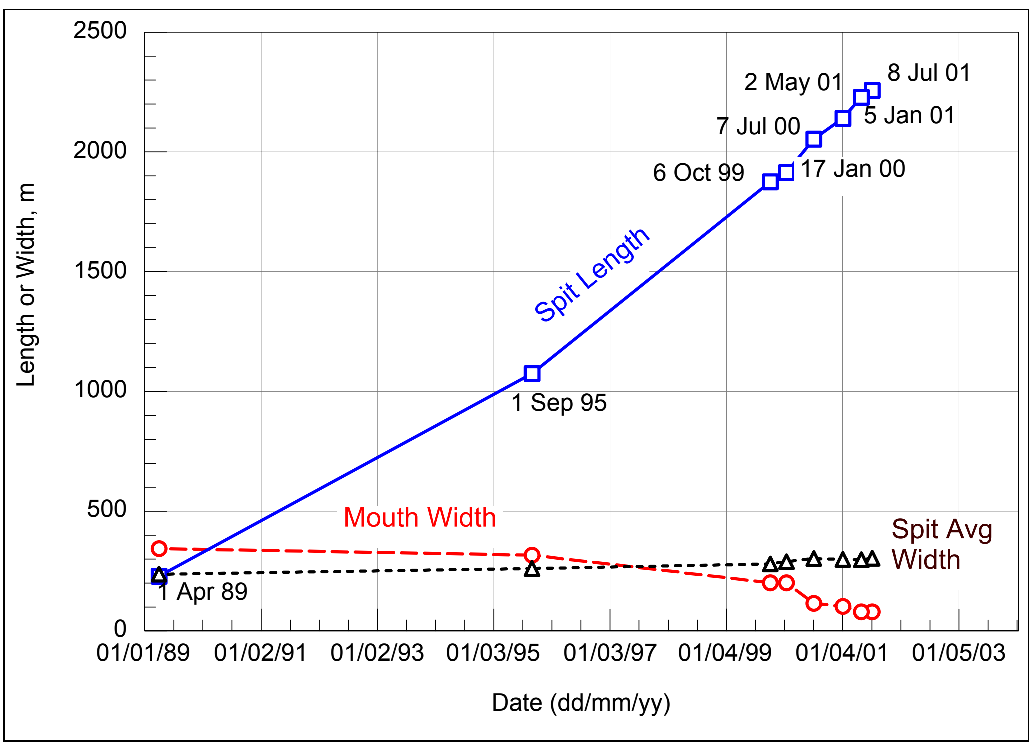

Figure 10. San Bernard River mouth spit length and width and width of river mouth

Murrells Inlet, SC. Murrells Inlet provides a clear example of an inlet which migrated due to spit growth while in its natural state and, when stabilized with a dual jetty system, illustrated spit growth over the north weir jetty towards the interior navigation channel. Figure 11 illustrates the inlet's migration before jetties were constructed. Between 1950 and 1963, the inlet migrated north to south (left to right), with a recurved spit fed from the beach on the left side and perhaps supplemented by sand moving shoreward from the left portion of the ebb shoal as the main ebb channel migrated to the south (right). During construction and after the twin jetty system was built at Murrells Inlet, sand moved over the mean tide level weir. Sand bypassed the dredged sediment basin and moved along the inner bank shoreline as a spit.

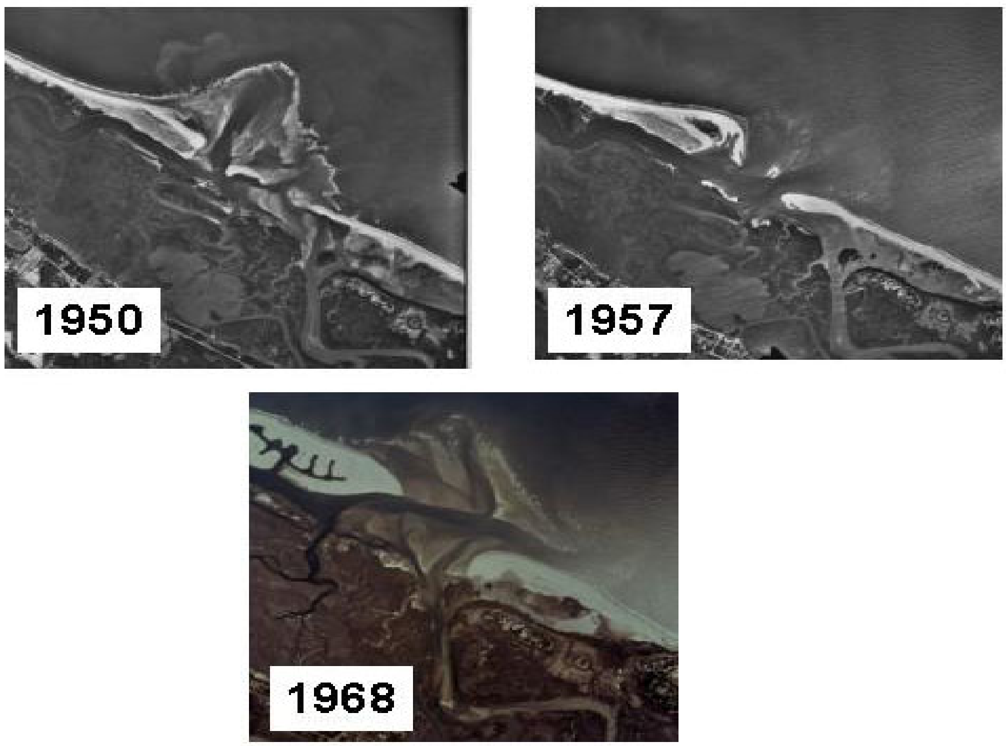

Figure 11. Murrells Inlet, SC

Figure 12 shows two spits on the inside of the inlet. The first, or top spit was formed during construction of the jetty system, which was initiated by construction of the north weir jetty. This permitted wave energy from the southeast to enter the inlet and recurve the first spit. The weir was at mid-tide elevation so that flood currents and waves could move sediment into the deposition basin region. The sand moved in as a spit, hugging the shoreline rather than disbursing in a broader pattern into the basin. The second spit formed once the second, or southern jetty was completed.

The trajectories of the tips of the two spits relative to the coordinate system given in Figure 12 are plotted in Figure 13. The baseline serves as the x-axis and the vertical reference, the y-axis. Spit 1, or the first spit was recurved to the right in response to waves from the southeast. Once the south jetty was completed, the spit stopped movement along the positive x-axis and was cut back along the y-axis. With the full jetty system in place, the second spit (Spit 2) grew toward

the inner channel until it reached the inner channel and was recurved parallel to the axis of the inner channel by ebb currents (note movement of Spit 2 to the left, or toward negative x-values in Figure 13).

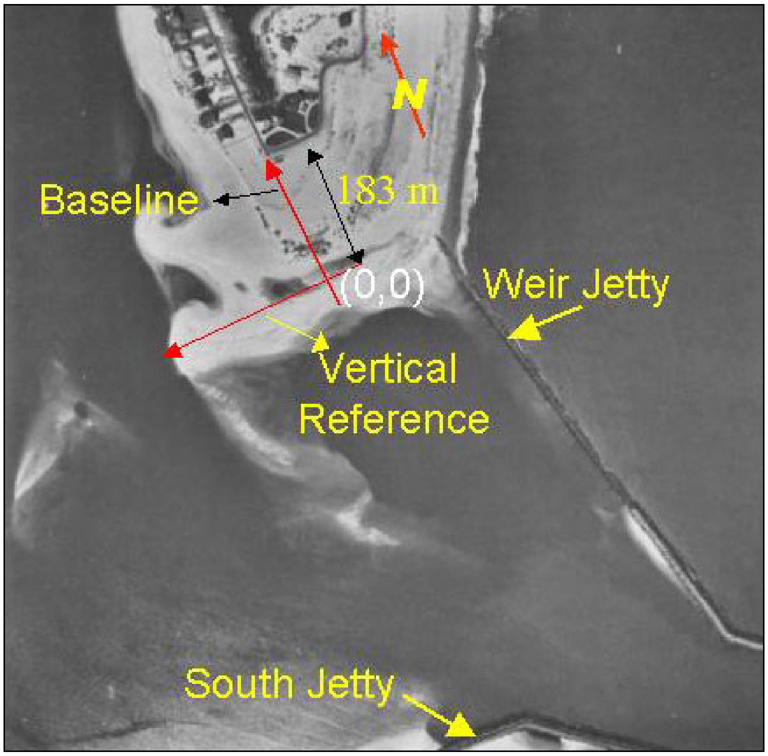

Figure 12. Spit growth at Murrells Inlet, SC, just after jetty construction, 6 March, 1981

Eventually Spit 2 partially functioned in directing sediment into the deposition basin from the inner channel side, as seen in Figure 12. Early ebb currents are directed toward the weir jetty, but as the water elevation falls below the mid-tide elevation of the weir, channel currents are directed out between the jetties. A detailed examination of the spit response with photographs is found in Seabergh (1987).

PHYSICAL MODEL OF SPIT GROWTH: Spit evolution was examined in an Idealized Inlet Model installed at the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (Seabergh 1999). This physical model supports basic and applied research through the Coastal Inlets Research Program. The concrete basin (46 m wide, 99 m long, 0.6 m deep) contains an ocean and bay separated by an inlet. A movable wave generator on the ocean side creates waves of fixed direction and variable height and period. Tidal cycle water level variation can be created or steady-state ebb/flood flows can be produced for a given water level with a combination of pumps, storage tanks, valves and sump.

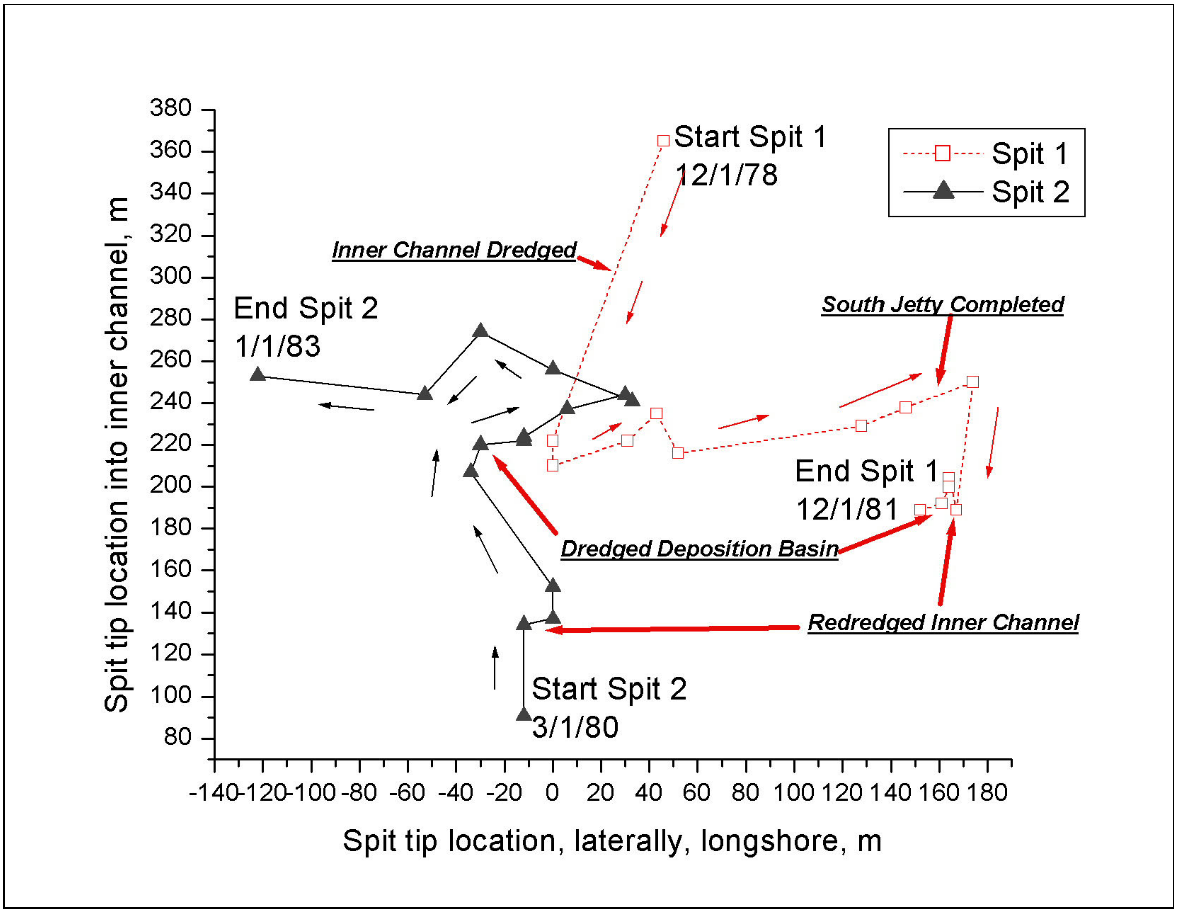

Figure 13. Trajectories of spit tips at Murrells Inlet, SC, from 12/78 through 1/83
(see Figure 12 for axes references)

The physical model study examined dependencies of geometric parameters and provided observations of integrated spit processes. A 0.13-mm uniform quartz sand was placed along the updrift barrier island as a 10-cm-thick veneer that tapered towards the offshore and was truncated approximately 2.1 m updrift of the inlet entrance. Figure 14 shows the growth of a spit towards the inlet channel. Waves approached at a 20-deg angle to the shore and broke, creating a longshore current. Twenty-two cases were run with different wave height and period, fixed water level, or with tide. Cases were run with current in the inlet, with a steady flood flow, with a reversing tidal flow. Wave height varied between 2.4 and 3.4 cm, and wave period between 1 and 2.2 sec.

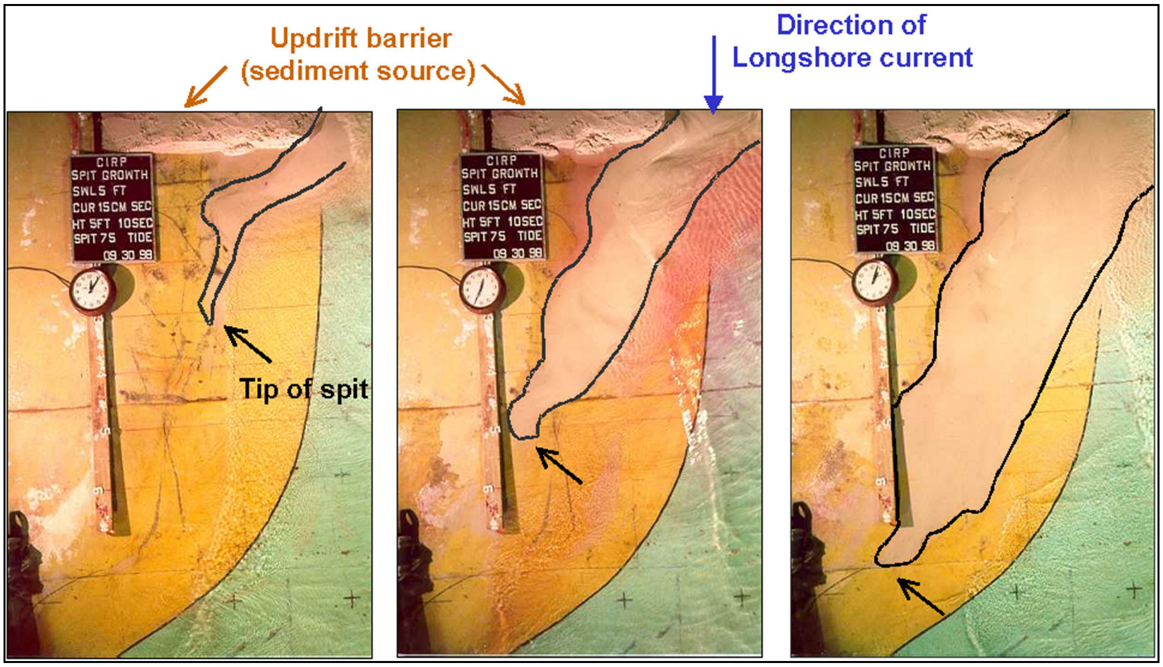

Figure 14. Spit growth at an inlet in a physical model

Some trends noted in the physical model work included the increased elongation rate into the inlet with flood currents present as compared to the no-current situation; however, spit length eventually halted as the flood current removal of sediment balanced incoming sediment. For the no-current experiment, spit length continued to grow, but with a decreasing rate for the limited experiment duration. Spit width reached equilibrium under constant wave action. Also a direct correlation was found whereby spit width increased with increasing wave period, increasing wave height, and increasing tide range. For spits in an early development stage, wave overtopping of the spit would create pooling behind the spit in some cases, which could break through the more distant portions of the spit, slowing growth until sediment had bridged the gap. Some of the processes observed in the physical model were described mathematically as discussed in the next section.

MATHEMATICAL MODEL OF SPIT GROWTH: The following material was adapted from Kraus (1999). If it can be assumed that a spit maintains a simple geometric form, then measurement of its width and length through time can give an estimate of the left-directed or right-directed longshore sediment transport rate along a coast. Viewing Figure 15 for notation, it is assumed that:

a. The spit elongates solely by gradients in longshore sediment transport rate Q;
b. The spit maintains a constant width, W;
c. Active movement of the spit occurs within the vertical distance D composed of the sum of the berm elevation B and depth of closure D_C measured from a common datum such as mean water level; and
d. Contours of the spit move in parallel over representative time scales.

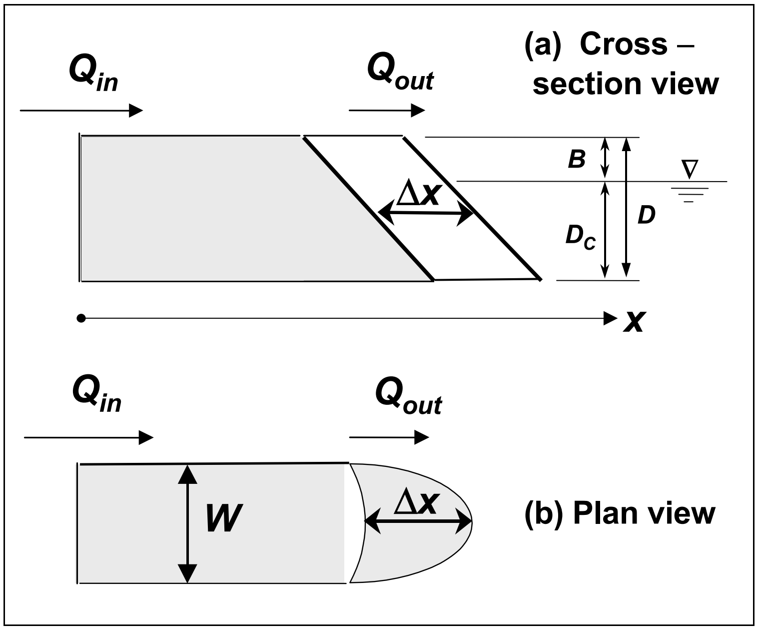

Figure 15. Definition sketch for mathematical model of spit growth

Viewing Figure 15, in time interval Δt, the volume change ΔV equals $WD\Delta x$, for which the depth of active motion is $D = B + D_C$ (sum of the berm elevation and the depth of closure); and Δx is the increment of change in length of the spit in time Δt. By assumption, the volume change is equal to the volume entering minus that leaving during the time interval, i.e., $\Delta t(Q_{in} - Q_{out})$. In the limit, the sand conservation equation becomes

$$\frac{dx}{dt} = \frac{1}{WD}(Q_{in} - Q_{out}) \tag{1}$$

Solutions of Equation 1 are determined after specifying an initial condition, boundary condition, and functional forms for the transport rates and other parameters, as appropriate. Three cases with different boundary and forcing conditions are discussed here (see Kraus (1999) for others).

Case 1: Unrestricted Spit Growth. If a spit can elongate without restriction over the time period under consideration, then $Q_{out} = 0$ (no sediment leaves or enters the spit from the distal end or channel side). As in input transport rate, suppose

$$Q_{in} = \bar{Q} + \frac{Q'}{2}\cos(\sigma t) \tag{2}$$

where $\bar{Q}$ = time-mean longshore sediment transport rate from the updrift (left or right side of the spit); $Q'/2$ = amplitude of a sinusoidal fluctuating rate; and σ = angular frequency of the motion, for example, 2π/year. Then, if the initial position of the spit at $t = 0$ is located at $x = 0$, the solution of Equation 1 for the location of the tip of the spit, denoted as x_S, is

$$x_S = \frac{1}{WD}\left(\overline{Q}t + \frac{Q'}{2\sigma}\sin(\sigma t)\right) \tag{3}$$

Equation 3 shows that spit elongation is directly proportional to the longshore sediment transport rate and to elapsed time, as modified by the fluctuating rate, and inversely proportional to spit width and depth of active movement. It is feasible that the spit could shorten during a transport reversal, depending on the magnitudes of $\overline{Q}$, Q' , and σ.

The elongation rate of the time-dependent term in Equation 3 depends inversely on the angular frequency. This means that, for the same amplitude of transport $Q'/2$, a higher-frequency motion will damp more quickly and be less perceptible than a lower-frequency motion. As an example, suppose $Q_{in} = \overline{Q}$ = 100,000 m^3/year, D = 5 m, and W = 100 m. In addition, suppose that two sinusoidal forcings occur with respective angular frequencies of 2π/(1 year) and 2π/(1 month) and equal amplitude $Q'/2 = 50{,}000$ m^3/year. Then, in 1 year, x_S = 200 m, which is a plausible distance. Figure 16 shows the linear growth of the spit as produced by the mean transport rate and the growth as modified by the two terms. The response of the spit to the monthly change in transport rate is barely perceptible despite having the same amplitude as the annual fluctuation.

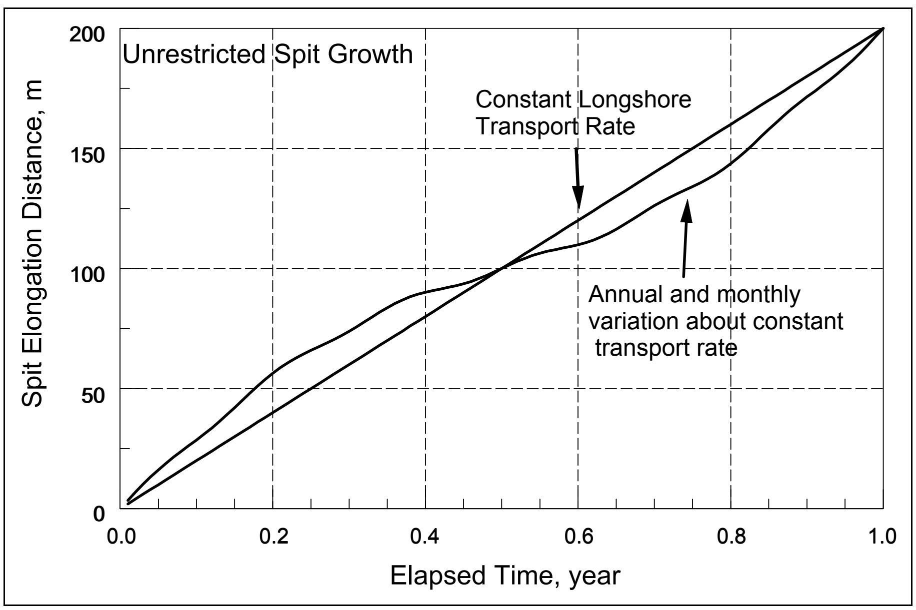

Figure 16. Unrestricted spit elongation, constant and with time variation in transport

For reference in interpreting the mean longshore transport rate, it can be shown that for N equi-spaced measurements of the rate, the net longshore transport rate $Q_n = N\overline{Q}$. For the remainder of this section, we take Q' = 0.

Case 2: Spit Growth Restricted by Presence of Inlet Channel. As an inlet spit elongates, eventually its motion will be modified by the presence of the inlet channel or of an obstacle. Encroachment of the spit to a channel will tend to push the channel in the direction of spit migration, forcing the channel to migrate as in the case of Democrat Point and Fire Island Inlet, as described in the "Background" section of this technical note. On the other hand, the tidal current will tend to transport material off the tip of the spit, slowing its growth as compared to that given in Equation 3 for unrestricted growth. At an inlet without stabilization structures, the competing processes of channel infilling by longshore transport and of channel scour by tidal and river discharge maintains a dynamic balance and equilibrium channel cross-sectional area. This balance has been examined quantitatively by Kraus (1998).

A phenomenological means of representing the scouring action of the channel in retarding spit growth is through an appropriate boundary condition for the transport rate Q_{out}. As one simple model of the boundary conditions, at a point x_o located far updrift of the channel, the transport is unrestricted, so $Q_{out} = 0$. At the location of the channel (or another impediment to longshore transport), x_C, the spit will not elongate further if $Q_{out} = Q_{in}$. One simple representation of Q_{out} between x_o and x_C is to take a linear increase with distance moved toward the channel, as

$$Q_{out} = \frac{(x - x_o)}{(x_C - x_o)} Q_{in} \tag{4}$$

which satisfies the boundary conditions as stated. The situation is shown in Figure 17.

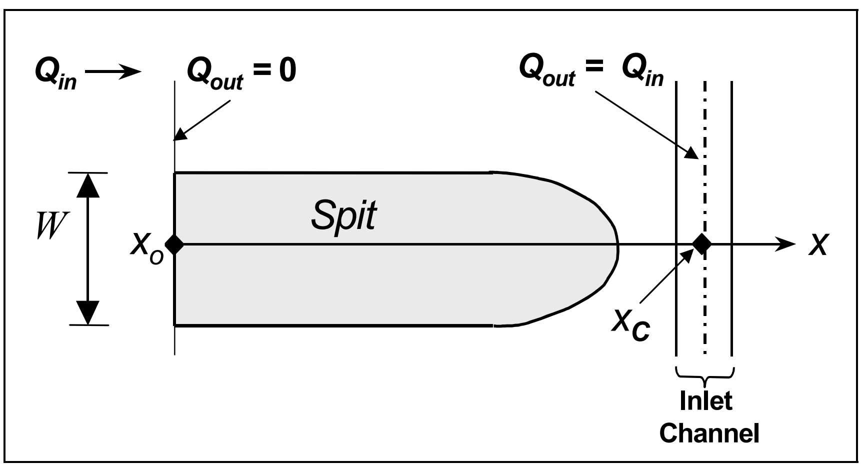

Figure 17. Definition sketch for spit approaching an inlet channel

The solution of the governing equation (Equation 1) for this situation of restricted elongation with $Q_{in} = \hat{Q}$ (constant transport rate) is

$$x_S = x_o e^{-t/\tau} + x_C \left(1 - e^{-t/\tau}\right) \tag{5}$$

where τ is a characteristic relaxation time for spit elongation given by

$$\tau = \frac{WD\left(x_C - x_o\right)}{\hat{Q}} \tag{6}$$

For the numbers in the previous example, and with a lateral extension of 100 m, we have τ = (100 m x 5 m x 100 m)/(100,000 m^3/year) = 0.5 year. This appears to be a reasonable time scale for representing the motion of an organized sediment body. For this value of τ, and with $x_o = 0$ without loss of generality, Equation 5 is plotted in Figure 18 as the line labeled "Constant depth" for constant depth of active movement. As seen in Equation 5, the rate of spit growth decreases exponentially as the spit approaches the channel.

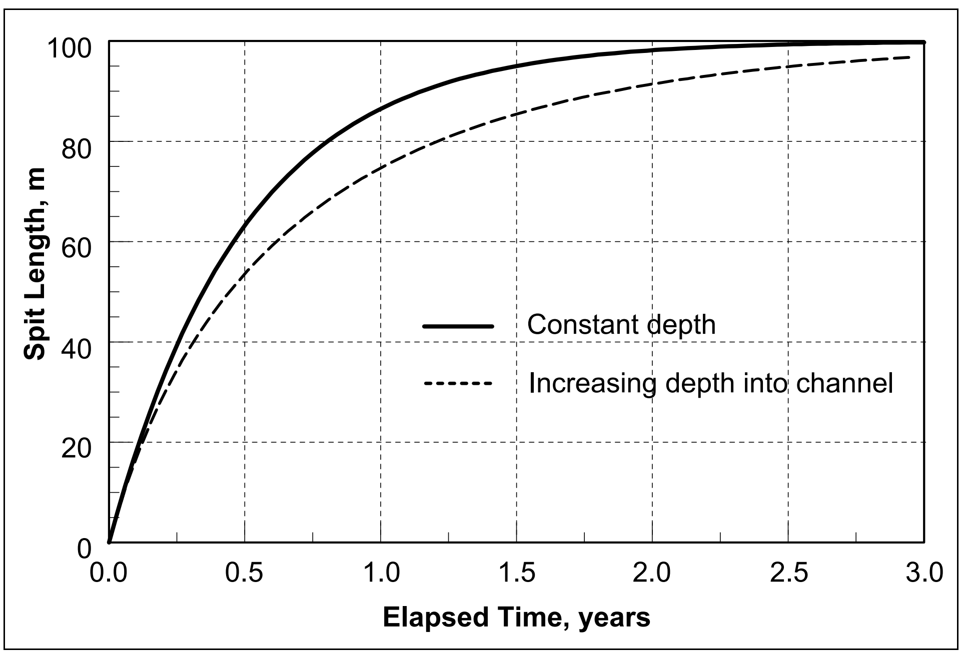

Figure 18. Prediction of spit elongation by analytical model

Case 3: Spit Growth Restricted by Inlet Channel and with Increasing *D*. This situation is the same as in the previous example, but is made more realistic by accounting for the depth of the channel. The depth of active movement is assumed to increase with approach of the spit to the channel, i.e., the inlet channel gorge is deeper than the ambient nearshore contours.

For simplicity in obtaining an analytical solution, the depth is taken to increase linearly with fixed slope from some depth D_o distant from the channel (at x_o). So,

$$D = D_o + Sx \tag{7}$$

where $S = dD/dx$ = slope into the channel. The governing equation (Equation 1), modified to include the x-dependence of D, becomes

$$\frac{dx}{dt} = \frac{1}{W\left(D_o + Sx\right)}\left(Q_{in} - Q_{out}\right) \tag{8}$$

The presence of the slope term, making the depth of active movement increase, acts to slow the rate of growth with increasing distance. Applying the same condition on the Q's as in the previous example, Equation 8 becomes

$$\frac{dx}{dt} = \frac{-\hat{Q}}{W\left(x_c - x_0\right)}\frac{x - x_c}{D_o - Sx} \tag{9}$$

The solution of this equation is

$$\ln\left(\frac{x - x_C}{x_o - x_C}\right) + \frac{S}{D_o - Sx_C}\left(x - x_C\right) = -\frac{t}{\tau'} \tag{10}$$

where τ' is the characteristic time scale as modified by the channel slope, as

$$\tau' = \tau\left(1 + \frac{S}{D_o}x_C\right) \tag{11}$$

If $S = 0$, Equation 10 reduces to Equation 5. With S nonzero, Equation 10 must be solved by iteration. The result with the same values as in the previous example and for $S = 0.01$ is plotted in Figure 18 with a dashed line. Because more material is required to elongate the spit as it approaches the (deeper) channel, a longer duration is necessary to extend the same length as for the case of constant depth of active movement.

CONCLUSIONS: Growth of spits into inlets, entrances, and river mouths can cause channel shoaling and, in an extreme case, channel closure. Restriction of water exchange by spit growth can also degrade water quality. It is also possible that a channel will migrate with because of growth of a spit, changing in location and alignment.

Documentation of the growth of emergent spits can be obtained from aerial photography, whereas submerged spits or shoals must be tracked by bathymetric survey. In the latter situation, it is necessary to survey outside the limits of the navigation channel to estimate the rate of approach of the shoal to the channel. Storms can accelerate growth of spits and shoals.

Quantification of spit growth by numerical models and physical models is possible. Documentation of spit growth can also provide an estimate of the left-directed or right-directed longshore sediment transport rate.

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